SYNOPSIS OF RESEARCH PROJECT

ON

RESPONSE OF SUMMER MAIZE TO BIOCHAR UNDER DEFICIT IRRIGATION REGIMES

UNDER THE GUIDANCE OF

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SYNOPSIS OF RESEARCH PROJECT

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9. Introduction

Zea mays commonly called corn or maize belongs to family *Poaceae*. Maize ranks as major grain crop worldwide and is one of the food cereal crops that can be grown in different seasons. Besides its use for human consumption, it is used as poultry feed, for extraction of edible oil, to produce ethanol as a biofuel, to prepared corn syrup a common sweetener used extensively in processed food and raw material in industry. Stalks used as a livestock feed, for paper and wallboard production; while core is used directly as fuel, to make charcoal and preparation of industrial solvents. Maize grain contains about 71.88 g carbohydrate, 8.84 g protein, 4.53 g fat, 2.15 g crude fibre, 1.50 g different minerals, 0.10 mg riboflavin, 0.12 mg vitamin C and 2.33 g ash on 100 g basis (Shah *et al.*, 2016).

Maize is widely cultivated throughout the world, covering about 197 million ha area with a production of about 1230 million tonnes and productivity around 6240 kg/ha. China and the USA are the major maize-producing countries, contributing around 21 percent and 18 percent to the global maize area, respectively. However, the USA ranks first in production, contributing about 31 per cent of world maize production, followed by China (23%), Brazil (9%) and Argentina (5%). India ranks 4th in terms of area (10.2 million ha) and 7th in terms of production (37.7 million tonnes), contributing about 3 percent of world

maize production. The USA leads in productivity (>11,000 kg/ha), followed by France, China and Brazil. India's average productivity is about 3,700 kg/ha (Anon., 2025).

Maize is the third most important cereal crop in India after rice and wheat and accounts for about 10 per cent of total food grain production in the country. The states of Karnataka, Madhya Pradesh, Maharashtra, and Rajasthan, as well as Uttar Pradesh are among the leading maize-producing states, together contributing about 65 percent of area and nearly 70 per cent of maize production across India.

In Gujarat, maize is cultivated in all three seasons and occupies about 0.36 million ha area with a production of about 0.77 million tonnes and productivity around 2120 kg/ha. Gujarat contributes about 3-4 percent of total maize area and about 2 percent of maize production of India. Tamil Nadu ranks first compared to other states in productivity (>7,500 kg/ha), followed by Andhra Pradesh and West Bengal, whereas Gujarat ranks around the middle group in productivity (Anon., 2025).

Biochar has become an important focus of global research due to its potential role in promoting sustainable agriculture. It serves as a long-term carbon sink in soils while also enhancing crop productivity. Biochar is a carbon-rich solid material produced through the carbonization of biomass via the process of pyrolysis, and it is widely recognized as an effective soil amendment and a means of carbon sequestration. Pyrolysis is a thermochemical process in which biomass is heated in the absence of oxygen, resulting in the formation of a stable carbon-rich residue. When this char is specifically produced for agricultural or environmental applications, it is referred to as biochar.

Producing biochar from agricultural residues and utilizing it in agriculture can play an important role in reducing the impacts of climate change (Zhang *et al*., 2012), improve the soil quality and management of waste generated from agricultural and forestry activities. Research suggests that biochar is capable of storing about 50 percent of the carbon available contained in the biomass material during pyrolysis (Madhavi, 2017b). Application of biochar to soil has been shown to enhance soil fertility and overall soil quality, leading to improved crop yields. Its benefits include increasing soil pH, enhancing water retention capacity, promoting the activity of beneficial fungi and microorganisms, improving cation exchange capacity (CEC), and reducing nutrient losses by better retention (Lehmann *et al*., 2006 and Lehmann, 2007). Such benefits contribute to increased crop productivity across different environmental conditions. Nutrient uptake and crop growth rate of maize increased with biochar applications (Yeboah *et al.*, 2016). Biochar offers multiple advantages for agricultural soils. It can be incorporated to enhance soil properties,

reduce reliance on fossil fuel–based fertilizers, and promote carbon sequestration (David and John, 2013).

Biochar application helps farmers in several ways: less fertilizer is needed because biochar absorbs and slowly releases nutrients to plants; biochar improves soil moisture retention and conserves water, securing the crops against drought; farmers spend less on seeds as emergence percentages increases; it increases the soil microbes and other soil-life density; it lessens the hardening of soils; it supports better growth of roots and helps in reclaiming degraded soils (Thakur and Gudade, 2017). Another advantage of biochar is that it can be used in all types of agricultural systems viz., organic, chemical, permaculture, mixed farming, natural farming, etc. (Cushion *et al*., 2010).

Availability of canal irrigation facility considerably increased the area under summer maize in Gujarat. Though the summer maize crop remains free from pest and diseases the productivity is too low. The reason for this might be low irrigation and nitrogen use efficiency that may be due to mismatch between crop requirement and supply.

Water is an essential constituent of living organisms for their growth and development. Moisture stress during the active crop growth phase results into cessation of growth as it influences the photosynthesis and other physio-chemical processes. Hence, water management studies have become an important aspect of research for irrigated crops. Under continuous evapo-transpiration situation of summer season and limited water holding capacity of light texture soil, proper scheduling of irrigation is must to maintain the soil at optimum moisture level. Irrigation scheduling studies provides information not only about water needs of the crop but also proper time for its application. The irrigation scheduling on the basis of growth stages fulfils the water requirement of Soil-Plant-Atmosphere continuum.

Irrigation regimes has a vital role in optimizing crop production. When water availability is lower than crop evapo-transpiration demand, leads to lower crop yield and protein content of maize. There is also a notable interaction between soil moisture and nutrient availability. It is commonly understood that the maximum advantage of fertilizer application occurs in irrigated environments, as sufficient water supply supports efficient nutrient absorption (Hussaini *et al*., 2008). Shinde *et al*. (2014) reported that, optimum level of irrigation at proper irrigation interval as per the local soil and climatic conditions are helpful in maintaining economically viable grain yield of maize.

Gujarat is recognized as one of the leading agriculturally advanced states in India with diversified cropping systems under irrigated and rainfed conditions. Extensive

quantities of agricultural residues from cereals, pulses, oilseeds and commercial crops are generated annually, particularly in canal command areas. However, a considerable proportion of these residues remains unutilized and is often disposed of through open-field burning, leading to loss of valuable nutrients and environmental pollution. With the expansion of irrigation facilities from the Sardar Sarovar Dam and its canal network, the area under summer maize and other irrigated crops has increased substantially in regions such as the Karjan Canal Command Area. After the harvest of sugarcane and *rabi* crops, large tracts of land remain available during summer, where intensive cropping is practiced due to assured canal irrigation. In this regard, conversion of mixed crop biomass into biochar and its application to soil offers a sustainable strategy for residue management, carbon sequestration and soil fertility enhancement. Integration of mixed crop-residue biochar with judicious irrigation and nutrient management may improve water and nutrient use efficiency, thereby enhance productivity of summer maize and enable efficient utilization of limited irrigation resources to support increasing food demand (Datta and Saxena, 2017).

10. Practical Utility of Research Project

Summer maize is a highly water-demanding crop, and declining irrigation water availability has made deficit irrigation a common practice in many maize-growing regions of India. Under such conditions, biochar application has a crucial role in improving soil moisture retention, reducing evaporation losses, and enhancing water use efficiency. Research evidence indicates that biochar-amended soils maintain higher available water content and reduce moisture deficiency in maize under limited irrigation (Lehmann and Joseph, 2015; Zhang *et al*., 2015). Therefore, this research will be practically useful in identifying suitable biochar application rates that can sustain growth and yield of summer maize under deficit irrigation regimes.

Deficit irrigation often limits nutrient accessibility and uptake, resulting in poor crop performance. Biochar, due to its large surface area and cation exchange capacity, improves nutrient retention and gradual nutrient release, leading to better nutrient use efficiency under moisture-stressed conditions (Laird *et al*., 2010; Major *et al*., 2010). The findings of this study will help in developing integrated water–nutrient management strategies for summer maize, thereby reducing fertilizer losses and improving crop productivity under reduced irrigation schedules.

Continuous application of biochar also contributes to long-term improvement in soil physical, chemical, and biological properties, as well as improved soil organic carbon,

improved aggregation, and enhanced soil microorganisms, which is critical for sustaining productivity under recurring water stress (Agegnehu *et al*., 2016). This research will provide practical evidence on the contribution of biochar to restoring soil health and improving resilience of maize-based cropping systems under deficit irrigation.

In light of the above-mentioned facts, a field experiment entitled "Response of summer maize to biochar under deficit irrigation regimes" is proposed to conduct at Instructional farm, Department of Agronomy, College of Agriculture, Junagadh Agricultural University, Junagadh during summer season of 2026 with the following objectives.

11. Objectives

1. To study the effect of different levels of biochar application on growth, yield and quality of maize
2. To evaluate the effect of deficit irrigation regimes on growth, yield and quality of maize
3. To find out the interaction effect of biochar and deficit irrigation regimes on maize if any
4. To study the effect of biochar and deficit irrigation regimes on physical and chemical properties of soil
5. To work out the economics of different treatments

12. Review of literature

12.1 Effect of biochar level

12.2 Effect of irrigation regimes

12.1 Interaction effect of biochar level and irrigation regimes

12.1.1 Effect of biochar level on plant growth parameters

The study demonstrated that the use of Acacia wood-based biochar at 5 t/ha significantly increased maize plant height and root length in comparison with the control (no biochar). This was measured in a pot culture experiment conducted by Saranya *et al*. (2011) at the Department of Agricultural Microbiology, Tamil Nadu Agricultural University, where biochar was applied at six levels (0, 5, 10, 15, 20, and 25 t/ha) with and without *Azospirillum* inoculation under three replications.

Widowati *et al*. (2012) executed a greenhouse experiment to study the effect of chicken manure and city waste compost and their biochar with as well as without nitrogen on growth and N requirement of maize. The result of study demonstrated that during first season of maize, all the combination involving organic and biochar with inorganic N fails

to reach a level of significance in respect of plant height, stem diameter, root length and dry biomass per ha over inorganic N application alone. Whereas residual impact of biochar on second season maize showed significant improvement in root length and dry weight (t/ha) with application of chicken manure biochar 30 t/ha + 145 kg/ha N and city waste biochar 30 t/ha + 145 kg/ha N compared to inorganic N (145 kg/ha) application alone.

A field experiment was set up to analyse the effect of biochar on growth parameters and crop at Coimbatore with five levels of biochar (0, 2.5, 5.0, 7.5 and 10 t/ha) and two levels of fertilizers (75 and 100% recommended dose of NPK) with as well as without FYM. Results demonstrated that applying biochar 7.5 and 10 t/ha substantially enhanced the number of monopodia, sympodia, fruiting points, number of bolls per plant and seed cotton yield (q/ha) over combined effect of NPK and FYM and lower levels of biochar. The result also showed that cotton germination remains unaffected owing to varying levels of biochar (Elangovan and Sekaran, 2014).

The outcomes suggested that the application of woody biochar at 200 g/pot significantly improved maize germination percentage, number of leaflets, seedling height, stem girth, number of roots per plant, and root length compared with the control. Ndor *et al*. (2015) reported these findings from a pot culture experiment conducted in Nigeria to examine the effect of biochar on early growth parameters of maize seedlings.

An experiment was carried out by Xiao *et al*. (2016) at China. Biochar was amended to a maize field at rates of 0, 10, 20 and 30 t/ha. The result showed that biochar addition substantially increased shoot dry matter, crop growth rate and root density than control treatment.

The results revealed that plant height and biomass of soybean increased markedly with biochar application, with the highest values recorded at the 40 t/ha dose. Sukartono and Sudantha (2016) undertook a field study to examine the effects of bio compost (0, 5, 10, and 15 t/ha) and biochar (0, 10, 20, 30, and 40 t/ha) on soybean growth, yield, and soil fertility status.

Sara *et al*. (2018) conducted an experiment at Peshawar, Pakistan and they concluded that biochar did not affect the germination and final plant stand of maize.

An experiment was conducted during summer season at the Quaker Research Farm of Texas Tech University, Lubbock on three biochar treatments (0, 15, 20 t/ha) were distributed in all irrigation levels to see the interaction effect on sweet corn performance and found that treatment 20 t/ha can sustain higher plant height among treatments Kafle *et al*. (2025).

12.1.2 Effect of biochar level on yield attribute and yield

Baronti *et al*. (2010) reported relative in maize grain yield following biochar application. The grain yield was 9.7, 10.3 and 12.1 t/ha in C- (control), C+ (residues of preceding maize) and CR (10 t/ha biochar) respectively; the percent increase in yield with C+ and CR was 6 and 24% respectively.

Major *et al*. (2010) studied the effect exerted by a single application of 0, 8 and 20 t/ha of biochar to a Colombian, Savanna, Oxisol for 4 years (2003–2006), under a maize-soybean rotation. The experimental result showed that maize grain yield did not differed significantly during the first year due to application biochar, however during 2004, 2005 and 2006 application of 20 t/ha biochar resulted 28, 30 and 140% increase in yield, respectively over control.

Arif *et al*. (2012) conducted an experiment on effect of biochar, FYM and mineral nitrogen alone and in combination on yield and yield components of maize. The experiment comprised of 6 fertilizer treatments i.e. control, nitrogen alone (150 kg/ha N), FYM alone (10 t/ha), biochar alone (30 t/ha), nitrogen (150 kg/ha N) + biochar (30 t/ha) and FYM (10 t/ha) + biochar (30 t/ha). Among the different treatments, application of 150 kg/ha N + 30 t/ha biochar was found promising in respect of plant height, ear length, number of rows per ear, number of grains per ear, test weight and grain and biological yield (kg/ha) over the remaining treatments; however, did not differ significantly from application of 150 kg/ha N for all the parameters, except number of grains per ear.

An experiment was set up to investigate how biochar amendment influences maize yield and greenhouse gas emissions in a calcareous loamy soil with low soil organic carbon in the Central China Plain by Zhang *et al*. (2012). Biochar was applied at rates of 0, 20 and 40 t/ha with (300 kg/ha Urea) or excluding N fertilization. The result of study noted that biochar additives significantly increased maize production but decreased GHGs. Under biochar additives, maize yield increased by 15.8% and 7.3% in the absence of nitrogen fertilization, and by 8.8% and 12.1% with nitrogen fertilization at application rates of 20 t/ha and 40 t/ha, respectively.

Cornelissen *et al*. (2013) carried out an experiment in Zambia on the impact of biochar on maize with different treatments (Non-fertilized control, Fertilized control, Maize cob biochar 0.8 t/ha, Maize cob biochar 4 t/ha, Wood biochar 0.8 t/ha and Wood biochar 4 t/ha) at five locations. They documented that the application of maize cob biochar 4 t/ha resulted in a significant increase in maize grain yield over fertilized control, more profoundly at acidic-sandy soil of Kaoma location.

An experimental results of Ndor *et al*. (2015) advocated that the application of 10 t/ha of woody biochar gave significantly higher grain weight per plant, 100-grain weight, and yield per ha in maize over no application.

Yang *et al*. (2015) implemented an experiment at Hebei Province of Northern China on the enhancement of crop yield by rice straw and corn stalk-derived biochar. They applied different dosages (1, 2, and 4 t/ha) of biochar and interpreted that biochar has potential to increment the yield levels of diverse crops (Corn, Sweet Potato, Peanut and Wheat). They indicated that rice straw biochar was more effective in enhancing corn yield, sweet potato, peanut, and winter wheat than corn stalk biochar. According to them, application of 1 to 2 t/ha of biochar could enhance the yield by 5%–15% and 4 t/ha of biochar up to 20%.

The outcomes indicated that application of biochar at 5 t/ha and higher rates significantly increased maize grain yield compared with the control in an Ultisol. Njoku *et al*. (2016) at the Teaching and Research Farm of the Faculty of Agriculture and Natural Resources Management, Ebonyi State University, a field experiment to assess the effects of biochar (0, 5, 10, and 15 t/ha) on soil chemical properties, carbon storage, and maize performance in southeastern Nigeria.

Application of biochar 30 t/ha significantly increased maize grain yield than control treatment (Xiao *et al*., 2016).

Sukartono and Sudantha (2016) studied the effect of five levels of biochar (0, 10, 20, 30 and 40 t/ha) on soybean. The result advocated that application of 10 t/ha biochar resulted 14 per cent increased in seed yield of soybean over control; however further increase in rate of biochar showed non-significant effect in this respect over 10 t biochar/ha.

An experiment was carried out by Yeboah *et al*. (2016) on effect of biochar type and rate of application on maize yield on an Ultisol in Ghana. They studied three different feed stock (corn cob, rice straw and cocoa pod husk) applied at three different rates (0, 2.5 and 5 t/ha) and observed that biochar irrespective of the feedstock type, have profound effect on maize grain yield over control. However, among the application rates, biochar 5 t/ha recorded a significantly higher yield over control.

Eazhilkrishna *et al.* (2017) conducted an experiment to analyse the effect of nutrient enriched biochar on yield of maize grown on Alfisol of Tamil Nadu. The nutrient enriched biochar (NEB) was prepared by utilizing sugarcane bagasse, molasses and press mud with the nutrient composition (NPK) of 7:7:7. The treatments were Absolute Control (T1), 50% RDF through NEB (T2), 75% RDF through NEB (T3), 100% RDF through NEB (T4), 125% RDF through NEB (T5), 50% RDF through NEB and 50% RDF through inorganic

fertilizers (T6) and 100% RDF through inorganic fertilizers (T7). The results of the field experiment demonstrated that grain yield and stover yield significantly increased with application of 100% RDF through NEB (T4) than the yield of nutrients supplied through 100% RDF through inorganic fertilizers (T7).

Madhavi *et al*. (2017a) carried out an experiment during *Kharif* 2013 at the College Farm, College of Agriculture, Rajendra Nagar, Hyderabad, Andhra Pradesh, on an Alfisol to assess most efficient combination of biochar, humic acid, and inorganic nutrient inputs to increase the productivity of maize. The study comprised of three factors; 1st fertilizers-(100 % RDF and 75 % RDF), 2nd biochar levels (0, 5 and 7.5 t/ha) and 3rd humic acid levels-(0 and 30 kg/ha). The result of study indicates that each increment in biochar level over control led to a significant rise in the grain and stover yield.

Sara *et al.* (2018) established a field experiment at Peshawar in 2018 and they noted that applying 40 t/ha biochar gave the highest grain yield over control in maize.

Ullah *et al*. (2018) conducted experiment to investigate the maize yield and nutrient concentration in its leaves as affected by biochar from different organic materials (wheat straw and sugarcane bagasse) at Koont Research Farm, Chakwal, Pakistan. The study included a control treatment and wheat straw biochar applied at a rate of 5 t/ha, and 10 t/ha, sugarcane bagasse–based biochar at 5 t/ha and 10 t/ha. The result revealed that with use of wheat straw–based biochar 10 t/ha caused a marked increase of 28.9% in biomass and 20.8% in grain yield in maize over control. Conversely, sugarcane bagasse biochar applied at 10 t/a significantly enhanced biomass by 27.6% and grain yield by 22.1% over the control treatment.

The outcomes suggested that softwood biochar application improved sweet corn yield compared with hardwood biochar and the control. Singh *et al*. (2023) demonstrated a field experiment on sandy loam soil at the Quaker Research Farm of Texas Tech University, where treatments included hardwood biochar, softwood biochar, and a non-biochar control to assess their effects on sweet corn performance under water stress condition.

12.1.3 Effect of biochar level on physical and chemical properties of soil

Hardie *et al*., (2009) determined that the application of the Acacia green waste biochar at 47 Mg/ha increased the proportion of pores within the plant available water content range, and thus the available soil water content. Similarly, Herath *et al*. (2013) noted that biochar addition led to a rise in the water retention capacity of the soil because it increased soil porosity due to the adsorptive nature of biochar.

In a three-year field study, application of biochar amendment at the rates of 0.23 and 0.45 kg/m^2 decreased the BD of 0 to 7.5 cm soil layer by 4.5 and 6.0 per cent, respectively (Chen *et al*., 2011).

Zhang *et al*. (2012) undertook an experiment to assess the influence of biochar amendment on a calcareous loamy soil poor in organic carbon in the Central China Plain. Biochar was applied at rates of 0, 20 and 40 t/ha either with or without N fertilization, and the results highlighted that biochar amendments lowered soil bulk density and increased soil total N contents and soil organic carbon but had no impact on soil mineral N.

Cornelissen *et al*. (2013) displayed that addition of either wood biochar or maize cob biochar to maize as a soil amendment 5% (mixed into the soils in the laboratory) increased the soil pH, CEC, base saturation, organic carbon content, plant available water and water retention at field capacity and permanent wilting point than non-amended soil.

Karer *et al*. (2013) noted that applying biochar 72 t/ha lower the bulk density and increased the EC, CEC, organic carbon, nitrogen-supplying potential and extractable potassium and phosphorus over no application at same nitrogen level in both silt loam (pH 7.4) and clay loam soil (pH 6.6). They also observed that PAW (plant available water) and WHC (water holding capacity) were significantly higher in the plots with the highest biochar treatment of 72 t/ha along with N supply than in the plots without biochar application. Several studies have reported alterations in water retention and WHC in soils treated with biochar. In another study, Kumar *et al*. (2013) stated that biochar application a rate of 0.5% proved sufficient to improve WHC of soil.

Application 5 and 10 t/ha woody biochar increased the pH, organic carbon, total nitrogen, available phosphorus, potassium, calcium, magnesium and CEC than control Ndor *et al*. (2015).

Yang *et al*. (2015) examined the effect of rice straw and corn-stalk derived biochar 2 and 4 t/ha on corn land, peanut land and sweet potato land soils. The result indicated that applying of biochar either 2 or 4 t/ha augmented the soil N, P, K and CEC relative to the control at all the three crops. However, a decrease in soil pH was observed under biochar-amended conditions corn land and peanut land soil over control; whereas in sweet potato land soil slight increase was noted over control.

Njoku *et al*. (2016) undertook an experiment at the Teaching and Research Farm of the Faculty of Agriculture and Natural Resources Management, Ebonyi State University, Abakaliki, to evaluate the effect of biochar on soil chemical properties, carbon storage, and maize performance in an Ultisol of southeastern Nigeria. The treatments consisted of

biochar applied at 0, 5, 10, and 15 t/ha. The findings indicated that biochar application significantly enhanced soil pH, total nitrogen, organic carbon, available phosphorus, and exchangeable bases (Ca, Mg, K, and Na), along with carbon storage (kg/ha), compared with the control,

Madhavi *et al*. (2017b) assessed the effect of fertilizer, biochar and humic acid levels on soil properties of Alfisol. They noted that soil pH, EC, CEC did not differ significantly after the harvest of maize due to application of biochar. However, slight increase in soil organic carbon was observed but it was at non-significant level.

Sara *et al*. (2018) reported that the application of biochar at 80 t/ha resulted in the highest nitrogen content in both grain and stover, along with a significantly greater total nitrogen uptake by maize compared to the control. They further observed that biochar application at 10 t/ha significantly enhanced soil organic carbon and mineral nitrogen while reducing bulk density, whereas electrical conductivity remained unaffected.

The results demonstrated that softwood biochar was more effective than hardwood biochar and the control in mitigating water stress and enhancing water productivity of sweet corn. This was documented by Singh *et al*. (2023), who executed a field trial on sandy loam soil at Lubbock, Texas, using treatments comprising hardwood biochar, softwood biochar, and a non-biochar control.

Wang *et al*. (2025) was set up an experiment during *Kharif* season at Shandong Irrigation Experiment Center Station, Changqing District, Jinan City, Shandong Province, China and they investigated three biochar application rates (T: 0 t/ha biochar, M: 15 t/ha biochar, and H: 30 t/ha biochar). The results showed biochar effectively mitigates soil moisture loss caused by deficit irrigation, significantly enhancing soil water retention, particularly at application rates from 0 to 15 t/ha.

12.1.4 Effect of biochar level on NPK status in soil

Major *et al*. (2010) nalyzed the effect of a single application of 0, 8 and 20 t/ha of biochar to a Colombian Savanna Oxisol for 4 years (2003–2006), under a maize-soybean rotation. The uptake research demonstrated that the use of biochar 20 t/ha improved the uptake of N, P, K, Ca, Mg, Cu and Sr in above ground parts of maize. However. biochar application showed a negative effect on Al accumulation in maize tissue. Furthermore, the availability of N, P, K, Ca, Mg, and Sr in soil increased with 20 t/ha biochar over control, similarly it also improved the organic carbon content of soil and slight increase in soil pH was also observed. However, biochar reduced the supply of Al in soil.

In a three-year field study, application of biochar amendment at the rates of 0.23 and 0.45 kg/m^2 decreased the BD of 0 to 7.5 cm soil layer by 4.5 and 6.0 per cent respectively (Chen *et al*., 2011).

Saranya *et al*. (2011) found that applying of even 5 t/ha biochar significantly improve the intake of N, P and K by maize. They further indicated that the combined application of 25 t/ha of biochar and Azospirillum resulted 1 to 2 fold increase in N uptake, 2 to 4 fold increase in P intake and 3 fold increase in K uptake of maize over a period of 120days after planting than control. In same experiment they observed that each increase in level of biochar from 5 to 25 t/ha significantly raised the soil organic carbon, available N, P, and K and also the population of N fixing bacteria (*Azospirillum* and *Diazotrophs*).

The study demonstrated that the use of maize stalk–derived biochar at 10 t/ha significantly boosted nutrient absorption (N, P, and K) in lettuce in contrast to the control and 5 t/ha treatments. The same rate also markedly improved soil properties, including pH, EC, organic carbon, CEC, total nitrogen, available phosphorus, and exchangeable bases (K, Na, Ca, and Mg). Nigussie *et al*. (2012) conducted this trial to examine the effects of biochar application (0, 5, and 10 t/ha) on soil properties and nutrient intake in lettuce.

Elangovan and Sekaran (2014) analyzed the effect of five graded levels of biochar (0, 2.5, 5.0, 7.5, and 10 t/ha) and two levels of fertilizers (75 and 100% recommended dose of NPK) with and without FYM on chemical properties of soil at Tamil Nadu Agricultural University, Coimbatore. The results of the study concluded that application of biochar positively influenced the accessible N, P and K status of soil over combined effect of NPK, and FYM. Furthermore each increase in biochar level results improvement in these properties.

Ndor *et al*. (2015) highlighted that application 5 and 10 t/ha woody biochar increased the pH, OC, total N, available P, potassium, calcium, magnesium and CEC than control.

Yang *et al*. (2015) documented the effect of rice straw and corn-stalk derived biochar at 2 and 4 t/ha on corn land, peanut land and sweet potato land soils. The result indicates that applying of biochar either 2 or 4 t/ha raised the soil nitrogen, phosphorus, K, and CEC over control at all the three crops. However, decrease in soil pH was observed under biochar-amended condition corn land and peanut land soil over control; whereas in sweet potato land soil slight increase ws noted over control.

Njoku *et al*. (2016) conducted a study at the Teaching and Research Farm of the Faculty of Agriculture and Natural Resources Management, Ebonyi State University, Abakaliki, to evaluate the effect of biochar on soil chemical properties, carbon storage, and

maize performance in an Ultisol of southeastern Nigeria. Biochar was applied at rates of 0, 5, 10, and 15 t/ha as treatment levels. The result revealed application of biochar significantly increased soil pH, total N, OC, available P, exchangeable bases (Ca, Mg, K, Na) and carbon storage (kg/ha) relative to the control.

Xiao *et al*. (2016) exhibited that among the different biochar rates i.e. 0, 10, 20 and 30 t/ha, application of biochar 30 t/ha increased the concentration and uptake of NPK in above ground plant parts of maize.

Sukartono and Sudantha (2016) conducted the trial to show the effect of bio compost and biochar on the growth and yield of soybean and soil fertility status. Bio compost consist of four rates: 0, 5. 10, and 15 t/ha and biochar consist of five rates: 0, 10, 20, 30 and 40 t/ha. The result of the research demonstrated that combinations of biocompost and biochar improved soybean nodulation by 67.22% which resulted increase in N intake by plants.

Eazhilkrishna *et al*. (2017) determined the impact of graded levels of nutrient enriched biochar prepared from sugar factory waste on intake of maize on Alfisol of Tamil Nadu. They indicated that 100 % RDF applied through NEB accumulated significantly more NPK in grain and stover than 100 % RDF through inorganic fertilizers.

Applying of 80 t/ha biochar gave highest nitrogen content in grain and stover, and showed a significant maximum total N intake by maize than control. They also noted that applying biochar 10 t/ha significantly increased soil organic carbon, mineral N and lowered the bulk density; while EC remained unaffected, Sara *et al*. (2018).

Ullah *et al*. (2018) executed a field trial at the Koont Research Farm, Chakwal, Pakistan, to investigate maize yield and leaf nutrient concentration as influenced by biochar derived from different organic materials, namely wheat straw and sugarcane bagasse. The treatments included a control and wheat straw biochar at 5 and 10 t ha^{-1}, as well as sugarcane bagasse biochar at 5 and 10 t ha^{-1}. The application of wheat straw biochar at 10 t ha^{-1} increased N, P, and K content in maize by 16.1%, 38.8%, and 33%, respectively, over the control. Similarly, sugarcane bagasse biochar applied at 10 t ha^{-1} significantly enhanced N, P, and K contents by 14.9%, 27.7%, and 30%, respectively, compared with the control.

12.1.5 Effect of Biochar level on Economics

Madhavi *et al.* (2017a) reported that application of 7.5 t biochar/ha along with 100% NPK (of recommended dose) gave highest gross monetary returns and net monetary returns; however, highest B:C ratio was obtained with application of 7.5 t biochar/ha + 75% NPK (recommended dose).

12.2 Effect of irrigation regimes

12.2.1 Effect of irrigation regimes growth parameters

Shirazi *et al*. (2011) carried out a field trial to find out the response of growth-contributing parameters of maize to water stress with five irrigation regimes (0, 0.2, 0.5, 0.8 and 1.0 IW/CPE ratio) during winter season. The highest plant height was recorded by them with scheduling of irrigation at 0.8 IW/CPE ratio compared to other treatments but it was similar to 0.5 IW/CPE ratio. Similar trend was also noticed in respect of root length.

Shivakumar *et al*. (2011) conducted field experimental at Agronomy Field Unit of the Main Research Station, University of Agricultural Sciences, Hebbal, Bangalore, India during the years 2002 and 2003 to assess the effect of irrigation schedules on growth, yield and quality of baby corn. They recorded the highest plant height, LAI, total dry matter per plant and green fodder yield when irrigation was planned at IW/CPE ratio 1.0 compared to other treatment. Similar, result was identified in case of plant dry weight by Reddy *et al*. (2012); they observed significantly maximum plant dry weight at IW/CPE ratio 1.0 but it was similar with scheduling of irrigation at 0.8 IW/CPE ratio.

Adamu *et al*. (2014) explored the effect of four irrigation levels (0.4, 0.6, 0.8 IW/CPE ratio and irrigation at critical growth stages) on maize during the *rabi* season of 2010–2011 at WMRC, Belvatagi, University of Agricultural Sciences, Dharwad, India. The experimental findings indicated that irrigation scheduling at 0.8 IW/CPE ratio significantly raised the above ground biomass, relative water content (%) in leaves at anthesis and SPAD value. However, it reduces the days to 50% anthesis, days to 50% silking and anthesis-silking interval than other treatments.

A field-based study was implemented by Shinde *et al*. (2014) at Instructional Farm, Department of Agronomy, Parbhani during *rabi* season of 2004-05 and 2005-06. They tested two irrigation schedule i.e. irrigation at 0.75 IW/CPE ratio and irrigation based on CGS. The result of study revealed that plant height (cm) and dry matter per plant (g) increased significantly when irrigation was planned at 0.75 IW/CPE ratio compared to CGS approach across both the years.

Dutta *et al*. (2015) executed an experiment at Gayeshpur, Nadia, West Bengal for assessing the impact of irrigation schedules (i.e. conventional irrigation, irrigation at 0.6, 0.8 and 1.0 IW/CPE ratio) on summer baby corn. The pooled results of three years showed the improved in plant height, LAI at 60 DAS, dry matter accumulation, and CGR at 40-60 DAS when irrigation was planned at the IW/CPE ratio of 1.0 compared to the other IW/CPE ratios; however, it did not differ significantly from conventional irrigation.

The results revealed that irrigation scheduling at an IW/CPE ratio of 0.75 significantly resulted in higher maize leaf area index, plant height, and crop growth rate (CGR) compared with rainfed and lower irrigation regimes. Roy *et al*. (2015) undertook a field experiment during the summer seasons of 2010 and 2011 at Jaguli (Mohanpur) Instructional Farm, Bidhan Chandra Krishi Viswavidyalaya, evaluating four irrigation treatments: rainfed (no mulch), rainfed (with mulch), and irrigated conditions at 0.5 IW/CPE, and irrigation at 0.75 IW/CPE.

Kader *et al*. (2016) implemented an experiment at Experimental Farm of Bangladesh Agricultural University, Mymenshingh, during summer, 2012. The experiment consisted of five irrigation treatments i.e. no irrigation (control), irrigations at 0.4, 0.6, 0.8 and 1.0 IW/CPE ratio. They noted the greatest plant height was registered when irrigation was scheduled at 0.8 IW/CPE ratio.

Niveditha and Nagavani (2016) implemented an experiment to determine the effect of irrigation and crop geometry on maize at S.V. Agriculture College, Tirupathi, (A.P), India. The result of their study indicated that scheduling of irrigation at IW/CPE ratio 1.0 resulted significant improvement in plant height (cm), LAI, dry matter (g) over IW/CPE ratio 0.6, but was equivalent to IW/CPE ratio 0.8. However, increased in levels of irrigation resulted in decrease in number of days required for 50% tasselling and silking.

The results revealed that scheduling irrigation at an IW/CPE ratio of 0.8 produced the highest plant height, leaf area, and above-ground dry matter (g) of maize compared with 0.4 and 0.6 IW/CPE ratios. Ajamirali and Halagalimath (2017) reported these findings from a field trial study conducted during rabi season 2015–16 at the University of Agricultural Sciences to evaluate the effects of irrigation scheduling and mulching on maize growth and yield.

Experimental results of Desai *et al*. (2017) indicated that the scheduling of irrigation at 0.8 IW/CPE produced significantly higher plant height and leaf number per plant, and delayed 50% tasseling and silking stages by requiring more days to attain them.

Abaza *et al*. (2023) executed a field trial at the experimental farm of water studies and research station, Egypt, through the two successive seasons of 2019 and 2020 and they observed that comparing the sowing date under different irrigation levels, a higher plant height (cm) and ear length was achieved with implementing $date_1$ under Ir_{100} & Ir_{70} irrigation levels, $date_2$ and $date_4$ under Ir_{100} irrigation levels, respectively.

The results indicated that full irrigation (100% ETc) produced the highest maize plant height, biomass, and leaf area index, though these values were statistically similar to those

obtained under 85% ETc. Likewise, the 70% ETc treatment showed plant height and biomass comparable to 85% ETc, whereas the 55% ETc level resulted in the lowest growth and LAI. These findings were reported from a summer season field experiment conducted at Gazhen-Fuafuat Kebele, Fogera woreda, Amhara Region, Ethiopia (Melkie *et al*., 2024)

A field trial study was undertaken in the summer season at the Quaker Research Farm, of Texas Tech University to evaluate four irrigation regimes: I_1 (100% ETc throughout), I_2 (80% ETc at vegetative followed by 60% ETc at reproductive), I_3 (60% ETc at vegetative followed by 80% ETc at reproductive), and I_4 (40% ETc throughout the season). The results showed that at 60 DAP (early reproductive), I_2 led to significantly increased plant height over I_4, while I_1, I_3, and I_4 were comparable. At 72 DAP (mid-reproductive), plant height under I_1, I_2, and I_3 remained similar but was significantly greater than I_4. By 100 DAP (late reproductive), plant height decreased by 7%, 6%, and 16% under I_2, I_3, and I_4, respectively, compared with full irrigation (I_1) (Kafle *et al*., 2025).

12.2.2 Effect of irrigation regimes on yield and yield attributes

Shirazi *et al*. (2011) focused on the effect of five irrigation regimes i.e. irrigation at 0, 0.2, 0.5, 0.8, 1.0 IW/CPE ratio on winter maize and observed that scheduling of irrigation at 0.5 IW/CPE ratio resulted improvement in number of ears per plant, ear length and breadth, number of kernels per ear and test weight which resulted in significantly higher grain and fodder yield

Reddy *et al*. (2012) performed an experiment during winter season of 2007-08 and 2008-09 in sandy clay loam soils of rice fallows at the Regional Agricultural Research Station, Warangal to find out the best irrigation schedule from three irrigation treatment (0.6, 0.8, 1.0 IW: CPE ratio). They found that irrigating maize crop at 1.0 IW/CPE ratio significantly enhanced the kernel weight per plant, the number of kernels per cob, 100-kernel weight (g), kernel and stover yield, over lower levels of irrigations but was similar with irrigation at 0.8 IW/CPE ratio for kernel yield (kg/ha). However, greatest water use efficiency was attained when irrigation was planned at 0.6 IW/CPE ratio.

Aulakh *et al*. (2013) observed that scheduling of irrigation to late *kharif* maize at IW/CPE ratio of 1.25 markedly raised the root density between 15-30 cm soil profile, grain yield, stover yield, shelling percentage and harvest index over lower levels of irrigation but it was equivalent to an IW/CPE ratio of 1.00.

A field trial study is conducted to study the effect of deficit water and plant population on maize. The experimental findings indicates that scheduling of irrigation at 0.8 IW/CPE ratio recorded significantly the highest kernel yield, stover yield and harvest index over 0.6

and 0.4 IW/CPE ratios. However, significantly higher water productivity achieved with irrigation scheduling at 0.4 IW/CPE ratio over rest of the irrigation treatments (Parthasarathi *et al*. 2013).

Adamu *et al*. (2014) implemented a field study at Water Management Research Center (WMRC), Belvatagi, University of Agricultural Science, Dharwad, India during 2010-2011 *rabi* season. In main plot, four irrigation levels (0.4, 0.6, 0.8 IW/CPE ratio and irrigation at critical growth stages of maize) and in sub plot, three maize hybrids were tested. The results revealed that scheduling of irrigation at 0.8 IW/CPE ratio significantly improved the cob length, number of grains per row and 100 seed weight which resulted in a markedly higher harvest index and grain yield over rest of irrigation treatments.

Shinde *et al*. (2014) documented that scheduling of irrigation at an IW/CPE ratio of 0.75 markedly raised the number of cobs per plant, 1000-seed weight, and grain and stover yield than scheduling of irrigation based on CGS approach in *rabi* maize. However, protein content and protein yield remains free from irrigation effect.

Dutta *et al*. (2015) undertook an experiment at Gayeshpur, Nadia, West Bengal to examine the effect of irrigation schedules (i.e. Conventional irrigation, irrigation at 0.6, 0.8 and 1.0 IW/CPE ratio) on summer baby corn. The Pooled results of three years showed indicates significantly higher yield attributes and cob yield of baby corn when irrigation was planned at IW/CPE ratio 1.0 than the other IW/CPE ratio, which was equivalent with conventional irrigation.

Roy *et al*. (2015) studied the effect of four different irrigation treatment i.e. rainfed without mulch; rainfed with mulch; irrigation at IW/CPE ratio of 0.5 and irrigation at IW/CPE ratio of 0.75 on summer maize during 2010-11 and 2011-12. They analyzed that the applying of irrigation at 0.5 IW/CPE ratio markedly raised the number of cobs per plant, the number of grains per cob, the length of cobs, test weight, grain yield and water use efficiency over rest of the treatments.

Kader *et al*. (2016) inspected the effect of five irrigation treatment *i.e.* no irrigation (control), irrigations at 0.4, 0.6, 0.8 and 1.0 IW/CPE ratio on summer maize during 2012 and noted that scheduling of irrigation at 1.0 IW/CPE ratio resulted improvement in number of grain line per cob, number of grains per line, number of grains per cob, cob length, cob perimeter, shell weight, 100 grains weight and grain yield. However significantly highest WUE on grain and total dry matter basis was achieved with no irrigation treatment followed by irrigation at 0.4 and 0.6 IW: CPE ratio.

Spring maize water productivity under a modified soil microenvironment was evaluated using three irrigation schedules (IW/CPE 1.25, 1.0, and 0.75) and four manuring practices (surface FYM, subsurface FYM at 15–25 cm between rows, digging and refilling, and control). The results demonstrated that irrigation at an IW/CPE ratio of 1.0 combined with subsurface manuring produced higher crop water productivity than other treatment combinations (Majumder *et al*., 2016).

Niveditha and Nagavani (2016) executed a field stydy on effect of different levels of irrigation and crop geometry on maize at S.V. Agriculture College, Tirupathi (A.P), India. They studied three irrigation levels i.e. irrigation at 0.6, 0.8 and 1.0 IW/CPE ratio. The analysis revealed that irrigation scheduling at 1.0 IW/CPE ratio markedly increased the cob length, cob girth, kernel weight per cob, hundred grain weight, grain yield and stover yield over 0.6 IW/CPE ratio, but was equivalent with irrigation at 0.8 IW/CPE ratio.

Ajamirali and Halagalimath (2017) examined the effect of three irrigation scheduling treatment i.e. irrigation at 0.4, 0.6 and 0.8 IW/CPE ratio on maize during *rabi* season of 2015-16. In this study they observed that scheduling of irrigation at 0.8 IW/CPE ratio markedly increased the test weight, grain and stover yield of maize. Whereas significantly maximum water use efficiency was achieved with irrigation at 0.4 IW/CPE ratio.

Desai *et al*. (2017) implemented an experiment at Navsari and they assessed that irrigation scheduling at 0.8 IW/CPE ratio gave markedly higher number of cobs per plant, cob length and cob girth, more grain yield per cob, grain yield per plant, test weight, grain yield and straw yield in maize.

Roja *et al*. (2017) researched that the effect of different irrigation levels; surface irrigation at 0.6, 0.8, 1.0, 1.2 IW/CPE ratios and drip irrigation at 0.6, 0.8, 1.0, 1.2 Epan on yield and yield attributes of maize. They found that drip irrigation scheduled at 1.2 Epan recorded higher yield and its attributes compared to other surface and drip irrigation treatments but 1.2 IW/CPE surface irrigation was promising in respect of no. of cobs per plant, cob weight, grain weight, no. of grains per cob test weight and shelling percent, grain yield and straw yield compared to other surface irrigation treatments.

Irrigation scheduling treatments comprising irrigation at critical growth stages and IW/CPE ratios of 1.0, 0.8, and 0.6 were evaluated for summer sweet corn. The results revealed that irrigation at an IW/CPE ratio of 1.0 yielded the higher green cob yield and fodder yield. This field trial was conducted at the Research Farm of Agronomy, College of Agriculture, Dhule (Sonpure *et al*., 2017).

A field study was implemented by Abaza *et al*. (2023) at the experimental farm of water studies and research station, Egypt, through the two successive seasons of 2019 and 2020 and they achieved that comparing the sowing date under different irrigation levels a number of rows per maize ear, grain index and highest ear weight was obtained with implementing date1 under Ir_{100} & Ir_{70} irrigation levels, $date_2$ and $date_4$ under Ir_{100} irrigation levels, respectively, although that significantly equaled the implementing of $date_5$ under Ir_{70}. Likewise, the lowest plant high was obtained by implementing $date_3$ under Ir_{100} & Ir_{70} irrigation levels.

Singh *et al*. (2023) executed a field experiment at Quaker Research Farm, Texas Tech University, Lubbock on sandy loam soil, and they compared irrigation regimes 100 % ET_c, 70 % and 40 % ET_c among those treatments 70 % ET_c gave higher ear yield and 40 % ETc gave higher harvest index of sweet corn.

Melkie *et al*. (2024) investigated an experiment during summer season at Gazhen-Fuafuat kebele, Fogera woreda, Amhara National Regional State, Ethiopia and they obtain that control treatment (100% ETc), representing non water-stressed conditions, yielded the higher yield, grain number per ear and ear length. Grain yield, number of grains per ear and ear length progressively decreased with increasing moisture stress levels (85% ETc, 70% ETc, and 55% ETc), with statistically significant differences observed between treatments.

12.2.3 Effect of irrigation regimes on physical and chemical properties of soil

Abaza *et al*. (2023) laid out a field experiment at the experimental farm of water studies and research station, Egypt, through the two successive seasons of 2019 and 2020 and they assessed that the best WUE of maize, it is just as effective to adopt Ir_{100} & Ir_{70} irrigation levels x $date_5$. Nevertheless, the implementation of Ir_{100} & Ir_{70} irrigation levels × $date_3$, causing the lowest decreases in maize WUE.

Singh *et al*. (2023) documented a field experiments at Quaker Research Farm, Texas Tech University, Lubbock on sandy loam soil, and they Compared to 100 % ET_c, 70 % and 40 % ET_c among those treatments 70 % ET_c gave higher water productivity of sweet corn.

Maximum irrigation water use efficiency was achieved under the 70% ETc treatment, followed by 55% ETc, with no significant difference between them. This indicated that 70% ETc is preferable to 55%, 85%, and 100% ETc for conserving irrigation water without notable yield reduction. These findings were indicated from a summer season field experiment conducted at Gazhen-Fuafuat Kebele, Fogera woreda, Amhara Region, Ethiopia (Melkie *et al*., 2024).

Wang *et al*. (2025) carried out an experiment during *kharif* at Shandong Irrigation Experiment Center Station, Changqing District, Jinan City, Shandong Province, China and they observed that experiment included three irrigation strategies (full irrigation (F: 70 %-80 % field capacity (θ_{fc})), deficit irrigation (D: 50 %-60 % θ_{fc}) during the jointing stage of maize and wheat (D_J), and deficit irrigation during the jointing stage and filling stage of maize and wheat (D_{J+F})) among the various treatments, the fully irrigated treatment (F) exhibited higher water-filled pore space compared to the deficit irrigation treatments (D_J and D_{J+F}).

12.2.4 Effect of irrigation regimes on NPK status in soil

Singh *et al*. (2007) conducted experiment at Pusa (Bihar) in winter season of 2000–2001 and 2001-2002 to find out the influence of levels of irrigation and NPK on nutrient uptake and quality parameter of winter maize + potato intercropping system. They studied four irrigation treatment i.e. irrigation at 0.5, 0.75, 1.00 and 1.25 IW/CPE ratio. The results of their study showed that, irrigation at 1.25 IW/CPE ratio resulted significantly higher intake of N, P and K in plant tissues than lower levels of irrigations but was at par with irrigation scheduled at 1.00 IW/CPE ratio. Similar trend was observed in case of grain yield per ha. On the contrary lowest level of irrigation i.e. irrigation at 0.5 IW/CPE ratio recorded significantly more protein content in grain and was similar with 0.75 irrigation level.

Significantly maximum crude protein, phosphorus, and potassium content in grain of baby corn when irrigation was scheduled at 1.0 IW/CPE ratio, Shivakumar *et al*. (2011).

Reddy *et al*. (2012) highlighted that scheduling of irrigation at 1.0 IW/CPE ratio significantly increased the uptake of nitrogen in kernel and stover as well as total intake over low levels of irrigation schedules in *rabi* maize cultivated after rice fallow under no till condition. They also observed that irrigation scheduling at 1.0 IW/CPE ratio resulted in slight improvement in soil nitrogen availability. The similar observations were also noted by Aulakh *et al*. (2013) in late *kharif* maize. They observed that higher level of irrigation i.e. irrigation scheduling at IW/CPE ratio of 1.25 resulted significantly higher accumulation of N, P and K in leaves, stalk, grain, cob and consequently significantly higher total intake over lower levels of irrigation, but it was equivalent with irrigation scheduling at IW/CPE ratio of 1.00.

Shinde *et al*. (2014) studied the effect of two irrigation schedules, i.e., irrigation at a 0.75 IW/CPE ratio, and irrigation based on CGS on winter maize during 2004-05 and 2005-06. The results of study presented that irrigation at 0.75 IW/CPE ratio resulted higher

uptake of nitrogen, phosphorus, and potassium over CGS based irrigation scheduling during both the years, however results fails to attain the statistical level of significance.

Abaza et al. (2023) conducted a field trial study at the experimental farm of the Water Studies and Research Station, Egypt. The findings indicated that, when comparing sowing dates under different irrigation levels, higher nitrogen content was achieved with the implementation of $date_2$ under Ir_{100} and Ir_{70} irrigation levels, which was statistically comparable to $date_3$ under Ir_{100} and Ir_{70}, as well as the combination of $date_5$ with Ir_{70}. In contrast, the lowest nitrogen content was recorded with the implementation of $date_1$ under both Ir_{100} and Ir_{70} irrigation levels.

12.2.5 Effect of irrigation regimes on economics

Reddy *et al*. (2012) obtained higher net returns of Rs. 31,788 and 35,605 during *rabi* season of 2007-08 and 2008-09, respectively when the crop was irrigated at IW/CPE ratio of 1.0 than lower levels of irrigations.

Sonpure *et al*. (2017) concluded that application of irrigation at IW/CPE ratio of 1.00 was optimum for achieving maximum gross monetary returns (₹ 243045/ha), net monetary returns (₹ 169113/ha) and higher benefit cost ratio (3.26) over 0.6 and 0.8 IW/CPE ratio.

12.3 Interaction effect of irrigation regimes and biochar level

12.3.1 Interaction effect of irrigation regimes and biochar level on plant growth

Majeed *et al*. (2018) executed an experiment to note the effect of three different biochars (Pin, Poplar, and Oak biochars), its four application rate (0, 1, 2, and 4%), and four different nitrogen rates (0, 70, 140, and 210 mg kg-1) on soil fertility, growth, and nutrient uptake of corn plants. They noted the higher leaf dry matter yield with a combined use of the poplar biochar, 4% biochar dose, and 140 mg/kg N application.

Leaf area index (LAI) of maize was consistently higher under the W_{15} irrigation regime than under W_{35} across all sampling stages in both years, and biochar application further enhanced LAI in both moisture regimes. Compared with the no-biochar control (B_0), biochar treatments (B_{15}, B_{30}, and B_{45}) increased LAI by 8.5–14.7% under W35 and 7.9–15.8% under W_{15} in 2015, and by 13.8–23.3% under W_{35} and 4.2–18.8% under W15 in 2016. Overall, LAI increases due to biochar ranged from 12.0% to 33.1% under the W15 regime across sampling dates. These results were obtained from a two-year maize field experiment conducted during 2015–2016 at the JiuZhuang Agricultural Research Experiment Station, Shuanghe County, Linhe City, Inner Mongolia, China (Yang *et al*., 2022).

12.3.2 Interaction effect of irrigation regimes and biochar level on yield and yield attributes

Zhang *et al*. (2012) implemented a field study to evaluate the impact of biochar application on maize yield and greenhouse gas emissions in a calcareous loamy soil low in organic carbon in the Central China Plain. Biochar was used at rates of 0, 20 and 40 t/ha with or without N fertilization. With N fertilization, urea was applied at 300 N kg/ha, of which 60% was applied as basal fertilizer and 40% as supplementary fertilizer during crop growth. Results stated that maize grain yield was increased by 15.8% and 7.3% without N fertilization, and by 8.8% and 12.1% with N fertilization under biochar amendment at 20 t/ha and 40 t/ha, respectively.

Reddy *et al*. (2012) conducted an experiment at Regional Agricultural Research Station, Warangal with different irrigation schedules i.e. Irrigation at 0.6, 0.8 and 1.0 IW/CPE ratio as main plots and three nitrogen doses i.e. 120, 180 and 240 N kg/ha as sub plots. They found that irrigating maize crop at an IW/CPE ratio of 1.0 and fertilization with 240 N kg/ha significantly superior to 0.6 but it was equivalent with a 0.8 IW/CPE ratio regarding plant dry weight, number of kernels per cob, kernel weight (g) per cob, kernel yield (kg/ha) and stover yield (kg/ha).

Alam Sher *et al*. (2016) carried out an experiment at Post Graduate Agriculture Research Station, University of Agriculture, Faisalabad on N use efficiency in maize (*Zea mays L*.) as affected by different organic amendments. They applied different nutrient sources i.e. biochar (BC), poultry manure (PM) and inorganic nitrogen (levels) to highlighted the performance of spring maize *(Zea mays L.)*. The results indicates that maximum grain yield, biological yield, number of grains per cob, 1000 grain weight and grain protein contents were recorded in treatment where 250 kg/ha nitrogen + 10 t/ha biochar and 10 t/ha poultry manure were applied.

Madhavi *et al*. (2017a) carried out an experiment on an Alfisol to find out most efficient combination of biochar, humic acid and inorganic sources of nutrients to rise the productivity of maize. The study comprised of three factors; 1st fertilizers- (100 % RDF and 75 % RDF), 2nd biochar levels (0, 5 and 7.5 t/ha) and 3rd humic acid levels- (0 and 30 kg/ha). The result of study revealed that treatment combination of 7.5 t/ha biochar with 100% NPK (recommended dose) gave highest grain and stover yield over rest of the biochar and fertilizer level combinations irrespective of humic acid effect.

Singh *et al*. (2023) documented a field experiment at Quaker Research Farm, Texas Tech University, Lubbock on sandy loam soil, and they results noted that the combined

influence of irrigation and biochar treatments for yield of sweet corn were non-significant during both years.

12.3.3 Interaction effect of irrigation regimes and biochar level on physical and chemical property of soil

Yang *et al*. (2022) researched that biochar applying at the rates of 15, 30, and 45 t/ha showed positive potential for improving soil moisture, comprehensive fertility index, above-ground growth and yield, and water-fertilizer productivity for the assigned water lower limits by the drip-fertigation system across over two years.

Singh *et al*. (2023) was implemented a field experiment at Quaker Research Farm, Texas Tech University, Lubbock on sandy loam soil, and the results assessed that the combined influence of irrigation and biochar treatments for water productivity of sweet corn were non-significant during both years.

12.3.4 Interaction effect of irrigation regimes and biochar level on NPK status in soil

Yang *et al*. (2022) conducted an experiment on maize and the result showed that one-time application of biochar treatment at a rate of 15 t/ha in the first growing season is recommended in terms of increasing the availability of N, P, K, and organic matter in sandy loam and also improve water-fertilizer productivity under irrigation water lower limit of-15 kPa soil matric potential.

12.3.5 Interaction effect of irrigation regimes and biochar level on economics

A field experiment conducted from February to June 2023 on loamy soils of Gujrat, Pakistan, evaluated three activated biochar levels (0, 5, and 10 t/ha) under full (100% ETc), partial (70% ETc), and severe (50% ETc) deficit irrigation across three maize hybrids (DK-2088, YH-5427, and DK-6317). The results showed that activated biochar application (5 and 10 t/ha) significantly improved net economic returns under all irrigation regimes, with the highest profitability recorded under full irrigation and the lowest under severe deficit. Among hybrids, DK-6317 produced the greatest returns, whereas non-amended plots consistently gave the lowest returns irrespective of irrigation level (Naz *et al*., 2025).

13. Materials and Methods

Table 1. Details regarding the crop to be sown

Crop and Cultivar	Maize and King - 8666
Spacing	60 x 20 cm
Seed rate	15-20 Kg/ha
Plot size	**Gross**: 5.0 m x 3.60 m **Net:** 4.0 m x 2.70 m
RDF	120-60-40 kg N, P_2O_5 and K_2O/ha

13.1 Location

Instructional Farm, Department of Agronomy, College of Agriculture, Junagadh Agricultural University, Junagadh

13.2 Year and season of experiment

Year: 2026 & 2027, summer season

13.3 Experimental design

Split plot design

13.4 Treatment details

A. Main plot (Irrigation regimes)

I_1: Number of irrigations – 9 (8 + 1 common after sowing)

I_2: Number of irrigations – 7 (6 + 1 common after sowing)

I_3: Number of irrigations – 5 (4 + 1 common after sowing)

B. Sub plot (Biochar level)

B_0 – Biochar 0 t/ha

B_1 – Biochar 2 t/ha

B_2 – Biochar 4 t/ha

B_3 – Biochar 6 t/ha

Note- The irrigations will be given as per the details given below

I_1: Number of irrigations – 9 (8 + 1 common after sowing)

1. Seedling stage – 10 DAS
2. Fourth leaf stage – 12-18 DAS
3. Knee high stage – 20-25 DAS
4. Grand growth stage – 30-40 DAS
5. Tasselling stage – 45-50 DAS
6. Silking stage – 50-55 DAS
7. Grain Filling stage – 60-70 DAS
8. Dough stage – 70-80 DAS

I_2: Number of irrigations – 7 (6 + 1 common after sowing)

1. Seedling stage – 10 DAS
2. Knee high stage – 20-25 DAS
3. Grand growth stage – 30-40 DAS
4. Tasselling stage – 45-50 DAS
5. Silking stage – 50-55 DAS
6. Grain Filling stage – 70 DAS

I_3: Number of irrigations – 5 (4 + 1 common after sowing)

1. Knee high stage – 20-25 DAS
2. Tasselling stage – 45-50 DAS
3. Silking stage – 50-55 DAS
4. Early grain Filling stage – 60-70 DAS

13.5 Number of replications: Three **(**3)

13.6 Observations to be recorded

13.6.1 Growth Parameters

1. Initial plant population at 20 DAS
2. Final plant population at harvest
3. Plant height (cm) at 30, 60, 90 DAS and at harvest
4. Number of functional leaves per plant at 30, 60, 90 DAS at harvest
5. Dry matter accumulation (g/plant) at 30, 60, 90 DAS at harvest

13.6.2 Phenological Observations

1. Days to 50% tasseling
2. Days to 50% silking
3. Days to physiological maturity

13.6.3 Yield Attributes

1. Number of cobs per plant
2. Cob length (cm)
3. Cob girth (cm)
4. Number of grains per cob
5. Number of lines per cob
6. 100-grain weight (g)

13.6.4 Yield

1. Grain yield (kg/ha)
2. Stover yield (kg/ha)
3. Harvest index (%)

13.6.5 Quality parameters

1. Protein content (%)
2. Protein yield (kg/ha)
3. Sugar content (%)

13.6.6 Soil and Water Parameters

1. Soil moisture content at 0-20 cm depth before and after each irrigation

2. Water use efficiency (kg/ha/mm)
3. Water holding capacity (%)
4. Bulk density (g/cm3)
5. Porosity (%)
6. Soil organic carbon at initial and after harvest
7. Available N, P_2O_5 and K_2O at initial and after harvest

13.6.7 Economics

1. Gross returns (Rs./ha)
2. Cost of cultivation (Rs./ha)
3. Net returns (Rs./ha)
4. Benefit Cost Ratio (B:C ratio)

Table 2: Details of methods used for estimation of nutrient status in soil

Sr No.	Parameters	Methods	References
1.	Available N in the soil	Alkaline permanganate method	Subbiah and Asija (1956)
2.	Available P_2O_5 in the soil	Olsen's method	Olsen *et al.* (1954)
3.	Available K_2O in the soil	Flame photometric method	Jackson (1974)
4.	Available organic carbon in the soil	Walkley-Black wet oxidation method	Walkley and Black (1934)
5.	Bulk density of the soil	Cone penetrometer method	Piper (1950)

14. Statistical analysis

The data will be subjected to statistical analysis by adopting appropriate analysis of variance as described by Gomez and Gomez (1984). Wherever, the F values found significant at 5 per cent level of probability, the critical difference (CD) values will be computed for making comparison among the treatment means. In order to establish interrelationship between various components, coefficients of correlation and regression equations will be computed as described by Panse and Sukhatme (1985).

15. References

Abaza, A. S., Elshamly, A. M., Alwahibi, M. S., Elshikh, M. S. and Ditta, A. (2023). Impact of different sowing dates and irrigation levels on NPK absorption, yield and water use efficiency of maize. *Scientific reports*, **13**(1): 12,956.

Adamu, C., Kumar arvinda, B. N., Rajkumara, S., Patil, B. R., Patil, H. Y. and Kuligod, V. B. (2014). Physiological response, molecular analysis and water use efficiency of

maize *(Zea mays L.)* hybrids grown under various irrigation regimes. *African Journal of Biotechnology*, **13**(29): 2,966-2,976.

Agegnehu, G., Bass, A. M., Nelson, P. N., and Bird, M. I. (2016). Benefits of biochar and compost on soil quality and maize yield. *Agriculture, Ecosystems and Environment*, **225**: 114–125.

Ajamirali and Halagalimath, S. P. (2017). Effect of scheduling irrigation and mulching on growth and yield of maize *(Zea mays L.)*. *Journal of Farm Science,* **30**(1): 45-48.

Alam, S., Basit, A., Khan, A., Ameen, A., Hussain, S., Ahmad, M. I., Shakoor, A. and Abdullah, M. (2016). Nitrogen use efficiency in maize *(Zea mays L.)* as affected by different organic amendments. *Journal of Advanced Botany and Zoology*, **4**(1):1-5.

Anonymous (2025). Agricultural Statistics at Glance, Government of India, Ministry of Agriculture & Farmers Welfare, Department of Agriculture, Cooperation & Farmers Welfare, Directorate of Economics & Statistics. Government of India Publication, New Delhi, India: 74-255.

Arif M., Ali, A., Umair, M., Munsif, F., Ali, K., Inamullah, Saleem, M., and Ayub, M., (2012). Effect of biochar, FYM and mineral nitrogen alone and in combination on yield and yield components of maize. *Sarhad Journal Agriculture*, **28**(2):191-195.

Arif, M., Ali, K., Munsif, F., Ahmad, W., Ahmad, A. and Naveed, K. (2012). Effect of biochar, fym and nitrogen on weed and maize phenology. *Pakistan Jornal Weed Science Ressearch*, **18**(4): 475-484.

Aulakh, G. S., Vashist, K. K. and Mahal, S.S. (2013). Influence of irrigation regimes and nitrogen levels on root density, nutrient uptake and grain yield of August sown hybrid maize (*Zea mays L.*). *International Journal Plant Science*, **8** (2): 208-214.

Baronti, S., Alberti, G., Vedove, G. D., Gennaro, F. D., Fellet, G., Genesio, L., Mglietta, F., Peressotti, A and Vaccari, F. P. (2010). The biochar option to improve plant yields: first results from some field and pot experiments in Italy. *Italian Journal of Agronomy*, **5**: 3-11.

Chen, H. X., Du, Z. L., Guo, W and Zhang, Q. Z. (2011). Effects of biochar amendment on cropland soil bulk density, cation exchange capacity, and particulate organic matter content in the North China plain. *Chinese Journal of Applied Ecology*, **22**: 2,930-2,934.

Cornelissen, G., Martisen, V., Shitumbanuma, V., Alling, V., Breedveld, V., Rutherford, G. D., Sparrevik, D.W., M., Hale S.E., Obia, A. and Mulder, J. (2013). Biochar effect on

Maize yield and soil characteristics in five Conservation Farming sites in Zambia. *Agronomy*, **3**: 256-274.

Cushion, E., Whiteman, A. and Dieterle, G. (2010). Bioenergy development: issues and impacts for poverty and natural resource management. World Bank Publications.

Datta, D., and Saxena, S. C. (2017). Efficient recycling of crop residue. *Indian Farming*, **67** (04): 17-19.

David, M. Filiberto and John, L. (2013). Practicality of biochar additions to enhance soil and crop productivity. *Agriculture*, **3**: 715-725, doi:10.3390/agriculture3040715.

Desai, A. J., Patel, K. P., Chaudhari, M. P. and Patel, R. N. (2017). Effect of irrigation level and integrated nutrient management on growth and yield of *Rabi* maize (*Zea mays L.*) *J. of Pharmacognosy and Phytochemistry*, **1**: 990-992.

Dutta, D., Dutta, D. M. and Thentu, T. L. (2015). Effect of irrigation levels and planting geometry on growth, cob yield and water use efficiency of baby corn *(Zea mays L.) Journal of Crop and Weed*, **11**(2):105-110.

Eazhilkrishna, N., Thilagavathi, T. and Baskar, M. (2017). Effect of nutrient enriched biochar on yield and npk uptake of maize grown in *alfisol*. *International Journal of Current Microbiology Applied Science*, **6**(7): 1,326-1,334.

Elangovan, R. and Sekaran, N. C. (2014). Effect of biochar application on growth, yield and soil fertility status in cotton. *Asian Journal of Soil Science*, **9**(1): 41-49.

Gomez, K. A. and Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research*, 2nd Ed. John Wiley and Sons. New York, p. 639.

Hardie, M., Oliver, G., Bound, S., Clothier, B and Close, D. (2009). Effect of biochar application on soil water availability and hydraulic conductivity. Tasmanian Institute of Agriculture, University of Tasmania, Australia.

Herath, H. M. S. K., Arbestain, M. C and Hedley, M. (2013). Effect of biochar on soil physical properties in two contrasting soils: An *Alfisol* and an *Andisol*. Geoderma., **209-210**:188-197.

Hussaini, M. A. Ogunlela, V. B., Ramalan, A. A. and Falaki, A. M. (2008). Mineral composition of dry Season maize *(Zea mays L.)* in response to varying levels of nitrogen, phosphorus and irrigation at Kadawa, Nigeria. *World Journal of Agricultural Science*, **4**(6): 775-780.

Jackson, M. L. (1974). Soil chemical analysis. *Printice Hall of India Pvt. Ltd., New Delhi.*

Kader, M. A., Rahman, M. G. and Rakib, R. S. (2016). Effects of different irrigation levels on yield and water productivity of maize. *International Journal of Natural and Social Science*., **3**(4): 14-19.

Kafle, A., Singh, S., Deb, S., Simpson, C., and Ritchie, G. (2025). Physiology, growth and yield of sweet corn as affected by growth stage-based irrigation management and biochar application. *Crop Science*, **65** (2): e70021.

Karer, J., Wimmer, B., Zehetner, F., Kloss, S and Soja, G. (2013). Biochar application to temperate soils: Effects on nutrient uptake and crop yield under field conditions. *Agricultural and food science*, **22**: 390-403.

Kumar, S. K., Kumar, S. R., Mariappan, N and Surendar, K. K. (2013). Biochar boon to soil health and crop production. *African Journal of Agricultural Research*, **8** (38): 4726-4739.

Laird, D. A., Fleming, P., Wang, B., Horton, R., and Karlen, D. L. (2010). Impact of biochar on nutrient leaching from agricultural soils. *Geoderma*, **158**: 436–442.

Lehmann, J. (2007). Bio-energy in the black. *Frontiers in Ecology and the Environment*, **5**: 381–387.

Lehmann, J. and Joseph, S. (2015). *Biochar for Environmental Management Science, Technology and Implementation*. Routledge, London.

Lehmann, J., Gaunt, J. and Rondon, M. (2006). Bio-char sequestration in terrestrial ecosystems—*A review. Mitigation Adaptation Strategies Global Change*, **11**:395–419.

Madhavi, P., Sailaja, V., Ram Prakash T. and Hussain, S.A. (2017b). Characterization of biochar and humic acid and their effect on soil properties in maize. *International Journal of Current Microbiology and Applied Science*, **6**(9): 449-457.

Madhavi, P., Sailaja, V., Ram Prakkash T. and Hussain S. A. (2017a). Effect of fertilizers, biochar and humic acid on seed, stover yield, harvest index and economics of maize (*Zea mays L.*) grown on *Alfisols*. *International Journal of Pure and Applied Bioscience*, **5**(4): 766-770.

Majeed, A. J., Dikici, H. and Faruk, O. D. (2018). Effect of biochar and nitrogen applications on growth of corn (*Zea mays L.*) plants. *Turkish Journal of Agriculture - Food Science and Technology* **6**(3): 346-351.

Major, J., Rondon, M., Molina, D., Riha S. J. and Lehmann, J. (2010). Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and soil*, **333**: 117-128.

Majumder, D, Kingra, P. K. and Kukal S. S. (2016). Water productivity of spring maize under modified soil microenvironment. *Journal of Agrometeorology*, **18**(1):134-136.

Melkie, T., Jemberu, W. and Bitew, A. (2024). Optimizing water use efficiency in maize (*Zea mays L.*) production through deficit irrigation in Gazhen-Fuafuat Kebele, Northwest Ethiopia. *Frontiers in Agronomy*, **6**: 1490423.

Naz, Z., Rashid, A., and Jahan, S. (2025). Interactive effects of acacia biochar, maize hybrids, and irrigation levels on soil health and crop productivity. *PeerJ*, **13**: e20048.

Ndor, E., Dauda, S. N. and Azagaku, E. D. (2015). Response of maize varieties (*Zea mays L.*) to biochar amended soil in lafia. *American Journal of Experimental Agriculture*, **5**(6): 525 531.

Nigussie, A., Kissi, E., Misganaw, M. and Ambaw, G. (2012). Effect of biochar application on soil properties and nutrient uptake of lettuces (*lactuca sativa*) grown in chromium polluted soils. *American-Eurasian Journal Agricultural and Environment Science*, **12**(3): 369-376.

Niveditha, M. and Nagavani, A. V. (2016). Performance of hybrid maize at different irrigation levels and spacing under subsurface drip irrigation. *International Journal of Agricultural Science*, **12**(1): 1-5.

Njoku, C., Uguru, B. N. and Chibuike, C. C. (2016). Use of biochar to improve selected soil chemical properties, carbon storage and maize yield in an Ultisol in Abakaliki Ebonyi State. *International Journal of Environmental and Agriculture Research*, **2**(1):15-22.

Olsen, S. R.; Cole, C. V. Watanabe, F. S. and Dean, L. A., (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate, *Circular of V. S. Department of Agriculture*, pp. 939.

Panse, V. G. and Sukhatme, P. V. (1985). *Statistical Methods for Agricultural Workers*. Indian Council of Agricultural Research, New Delhi, pp. 87-89.

Parthasarathi, T., Vanitha, K. and Velu, G. (2013). Impact of irrigation water stress and plant population on water productivity and maize yield. *Madras Agricultural Journal*, **100**(1-3): 747-750.

Piper, C. S. (1950). *Soil and Plant Analysis. Inter-Science Publication Incorporation*, New York: 299.

Reddy, M. M., Padmaja, B. and Reddy, D. V. V. (2012). Response of maize (*Zea mays L.*) to irrigation scheduling and nitrogen doses under no till condition in rice fallows. *Journal of Research ANGRAU*, **40**(1): 6-12.

Roja, M., Kumar, K. S., Ramulu, V. and Kumar, M. G. (2017). Yield and yield attributes of maize (*Zea mays L.*) as influence by different surface and drip irrigation levels. *Environment and Ecology*, **35**(3c): 2,257-2,260.

Roy, S., Sengupta, A., Barman, M., Puste, A. M. and Gunri, S. K. (2015). Effect of irrigation and nutrient management on growth, yield, quality and water use of summer baby corn (*Zea mays L.*) in new alluvial zone of West Bengal. *Journal Crop and Weed*, **11**(2): 111-116.

Sara, Shah, Z. and Shah, T. (2018). Residual effect of biochar on soil properties and yield of maize (*Zea mays L.*) under different cropping systems. *Open Journal of Soil Science*, **8**: 16-35. https://doi.org/10.4236/ojss.2018.81002.

Saranya, K., Kumutha, K. and Krishnan, P. S. (2011). Influence of biochar and *Azospirillum* application on the growth of maize. *Madras Agricultural Journal*, **98**(4-6): 158-164.

Shah, T. J., Prasad, K. and Kumar, P. (2016). Maize—A potential source of human nutrition and health: *A review Cogent Food and Agriculture*, **2**: 1-9.

Shinde, S. A., Patange, M. J. and Dhage, S. J. (2014). Influence of irrigation schedules and integrated nutrient management on growth, yield and quality of *Rabi* maize (*Zea mays L.*). *International Journal of Current Microbiology and Applied Science*, **3**(12): 828-832.

Shirazi, S. M., Sholichin, M., Jameel, M., Akib, S. and Azizi, M. (2011). Effect of different irrigation regimes and nitrogenous fertilizer on yield and growth parameters of maize. *International Journal of Physical Science* **6**(4): 677-683.

Shivakumar, H. K., Ramachandrappa, B. K., Nanjappa, H. V. and Mudalagiriyappa. (2011). Effect of Phenophase based irrigation schedules on growth, yield and quality of baby corn (*Zea mays L.*). *Agricultural Science*, **2**(3): 267-272.

Singh, A. K., Roy, A. K. and Kaur, D. P. (2007). Effect of irrigation and NPK on nutrient uptake pattern and qualitative parameter in winter maize + potato intercropping system. *International Journal of Agricultural Science* **3**(1): 199-201.

Singh, M., Singh, S., Deb, S., and Ritchie, G. (2023). Root distribution, soil water depletion, and water productivity of sweet corn under deficit irrigation and biochar application. *Agricultural Water Management*, **279** :108192.

Sonpure, S. B., Ilhe, S. S. and Waidle, S. C. (2017). Influence of irrigation scheduling and mulching on yield and economics in summer sweet corn. *International Research Journal of Agricultural Economics and Statstics*, **8**(2): 315-319.

Subbiah, B. V. and Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science,* **25**: 259-260.

Sukartono and Sudantha, I. M. (2016). Agronomic response of soybeans and soil fertility status under application of biocompost and biochar on entisols Lombok, Eastern Indonesia. *IOSR journal of Environmental Science, Toxicology and Food Technology,* **10**(11): 06-11.

Thakur, M. R. and Gudade, B. A. (2017). Agronomic values of biochar. In: "*Conference book of the International Conference on Global research initiatives for sustainable agriculture and allied sciences*". 02-04, Dec. 2017, Udaipur, Rajasthan, India, PP. 61-65.

Ullah, Z., Akmal, M., Ahmed, M., Ali, M., Zaib, A. and Ziad, T. (2018). Effect of biochar on maize yield and yield components in rainfed conditions. *International Journal of Agronomy and Agricultural Research,* **12**(3): 46-51.

Wang, T., Cong, X., Yu, J., Zhao, H., Xu, L., Pang, G., and Xu, Z. (2025). Impact of biochar and deficit irrigation on greenhouse gas emissions reduction in maize-wheat rotation systems. *Agricultural Water Management*, **315**:109547.

Walkley, A. and Black, C.A. (1965). An examination of different methods for determining soil organic matter and proposed modifications of the chromic acid titration method. *Soil Science,* **37**: 29-38.

Widowati, Utomo, W. H., Guritno, B. and Soehono, L. A. (2012). The effect of biochar on the growth and N fertilizer requirement of Maize (*Zea mays L.*) in Green house Experiment. *Journal of Agricultural Science,* **4**(5): 255-262.

Xiao, Q., Zhu, LI-xi., Zhang, Hong-Pei., Li, Xiu-Yun, Shen, Yu-Fang. and Li, Shi-Qing. (2016). Soil amendment with biochar increases maize yields in a semi-arid region by improving soil quality and root growth. *Crop and Pasture Science,* **67**: 495–507.

Yang, W., Feng, G., Jia, Y., Yang, Y., Gao, X., Gao, L. and Qu, Z. (2022). Impact of single biochar application on maize growth and water-fertilizer productivity under different irrigation regimes. *Frontiers in Plant Science, **13***: 1006827.

Yang, Y. Shaoquiang Ma, Yi Zhao, M. Jing, Y. Xu and J. Chen. (2015). A field experiment on enhancement of crop yield by rice straw and corn stalk-derived biochar in northern china. *Sustainability,* **7**: 13,713-13,725.

Yeboah, E., Asamoah, G., Kofi, B. and Abunyewa A. A. (2016). Effect of biochar type and rate of application on maize yield indices and water use efficiency on an Ultisol in Ghana. *Energy Procedia,* **93**: 14-18.

Zhang, A., Liu, Y., Pan, G., Hussain, Q., Li, L., Zheng, J. and Zhang, X. (2012). Effect of biochar amendement on maize yield and greenhouse gas emissions from a soil organic carbon poor calcareous loamy soil from Central China Plain. *Plant and Soil,* **351**: 263-275

Zhang, Q., Du, Z., Lou, Y. and He, X. (2015). Short-term effects of biochar on soil properties and maize yield under deficit irrigation. *Agricultural Water Management,* **159**: 11–21.

Signature of Student **Signature of Major Guide**

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CERTIFICATE

This is to certify that **JAGMOHAN LODHA (Reg. No.: 1010125007)** has made an oral Presentation of the synopsis of research project entitled **"Response of summer maize to biochar under deficit irrigation regimes"** in **Department of Agronomy, College of Agriculture, JAU, Junagadh** dated **15/01/2026** in the presence of advisory committee members, other faculty Members and post graduate students. The student has incorporated all the suggestions**.**

Signature of major guide and members of the advisory committee

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